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None

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G2F
C4S

(54) **Optical interconnection system**

(57) The invention is concerned with the provision of optical connections between guided wave components on a common substrate. This is achieved by depositing a layer of photochromic material on the substrate between the components and forming waveguide channels in the photochromic layer. The photochromic material is capable of conversion between coloured and uncoloured states, which have different refractive indices. Waveguide channels are formed by selective conversion of regions of the photochromic material to the coloured using a focussed beam of U.V. light. Preferably the guided wave components are semiconductors.

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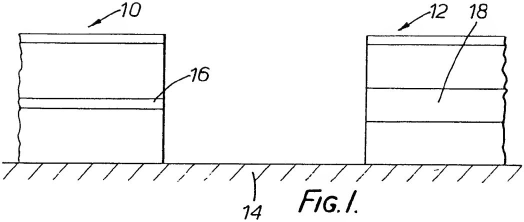


Fig. 1.

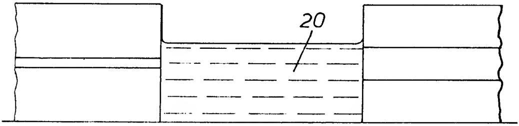


Fig. 2.

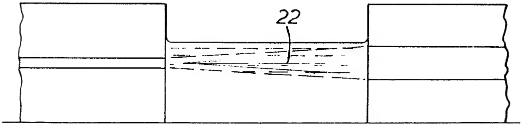


Fig. 3.

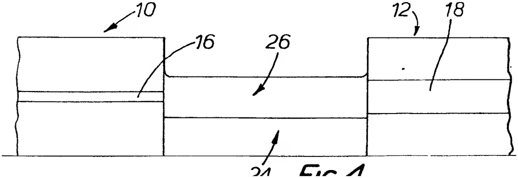


Fig. 4

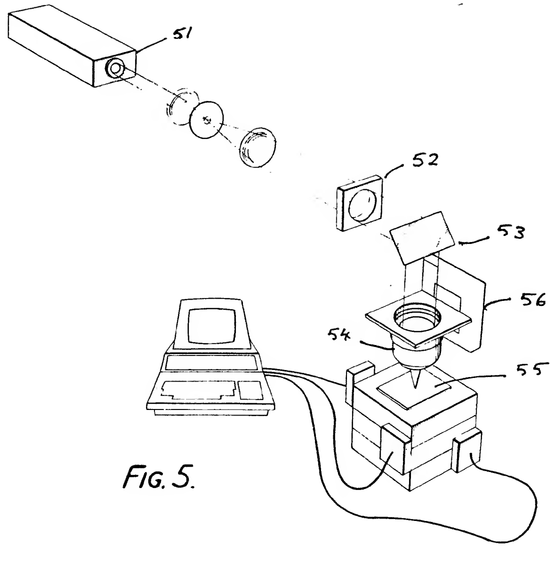


FIG. 5.

SPECIFICATION

Optical interconnection system

The present invention relates to optical interconnection systems and includes optical interconnection devices and a method for making such devices.

In the production of telecommunication circuits there is a need to provide optical interconnections between two or more separated semiconductor optical components formed on isolated areas of a single substrate. For example, effort has gone into producing optical interconnections between sources and detectors in GaInAsP grown on InP substrates. The common approach to the solution of this kind of problem consists of growing the appropriate interconnecting waveguide layers by controlled deposition of the appropriate semiconductor materials. This requires precise control of deposition parameters and alignment of the components to be optically connected. The method is prone to high optical propagation losses, and suffers from complexity. There are other situations in guided wave optics where similar interconnections are required.

The present invention provides an optical interconnection device which comprises a support, two or more guided wave components located thereon and a layer of a photochromic material therebetween, said photochromic material being capable of conversion between coloured and colourless states which have different refractive indices, and said layer having at least one wave guide channel which optically connects said components and which is formed therein by selective conversion of the photochromic material in the region defining the channel to a state different from that of the bulk material.

One series of photochromic compounds which have a significantly different refractive index in its coloured state compared with its uncoloured state is the series of fulgides and fulgimides described in British Patent No. 1,464,603. The compounds described in this patent exhibit a high quantum yield of conversion to the coloured state when irradiated with U.V.light at about 330-360 nm.

Wave guide channels may thus be formed in photochromic layers comprising such fulgides and fulgimides by reversible conversion to the coloured form using a U.V. laser.

Photochromic adamantylidene fulgides and fulgimides of the kind described in British Patent No,. 2,002,752 may also be used with advantage in the preparation of the photochromic layers since such compounds show excellent thermal stability in addition to a high quantum yield of conversion to the coloured forms.

It is also possible to utilise photochromic compounds of the kind disclosed in U.S. Patent No.4,182,629.

All the above cited patents may be referred to for details of the nature and methods of preparation of photochromic compounds useful in the manufacture of the photochromic layer.

The invention includes a method of making an optical interconnection device which comprises depositing on a support, having two or more guided wave components thereon, a layer comprising a photochromic compound dissolved or dispersed in a carrier composition to form a solid, light transmissive photochromic layer, said photochromic layer being capable of conversion between coloured and colourless states which have different refraction indices and forming at least one wave guide channel in said layer, which optically connects said components, by selectively converting photochromic material in a region defining the channel to the coloured state.

It is highly desirable to produce a photochromic layer which is free from small discontinuities or reticulations and is as flat as possible. Depending on the thickness required, the layer can be formed in one or more coating steps, it generally being preferable to form the layer in a single step. However, with larger thicknesses, the formation of a satisfactory layer can be achieved most easily by casting a multiplicity of superimposed films of a photochromic composition onto a support.

One technique for achieving this is to dissolve the selected photochromic compound in a solution or dispersion of a polymer and apply a single coating or successive coatings to a support, while drying each coating prior to the application of the succeeding coating. Various coating methods are satisfactory, including spin-coating and dip-coating.

In some circumstances, it may be possible to incorporate the photochromic compound in a polymerisable monomer composition, apply a coating of the monomer composition onto a support and cure or allow the monomer to cure to a solid, light-transmissive polymer film. The photochromic fulgides and fulgimides described in the above mentioned prior patents are able to withstand the conditions prevailing in a polymerising composition provided that the concentration of free radicals is not too high.

In preparing the solution or dispersion of the photochromic compound, we aim to achieve as high a concentration of the photochromic compound as practicable. For example, a photochromic fulgide may be dissolved in polymethyl methacrylate (PMMA) at a concentration of up to about 30% and the resulting mixture thinned with a solvent to obtain a solution of suitable viscosity for coating. Preferred solvents are ones of moderate volatility, e.g. solvents boiling above 100 - 120°C. Examples of other suitable polymers are poly(cyclohexyl)methacrylate poly(benzyl methacrylate).

The optical interconnection devices of this invention are particularly useful for connecting semiconductor components which incorporate optical waveguides, especially those used in communication systems. Wave guide components of this kind are described in U.S. Patent No. 4,245,883 and in the patents and other documents cited therein. This U.S. patent and the references cited in that patent may be consulted for details

of semiconductor wave guide components.

The interconnection system of this invention is suitable, for example, for connecting semiconductors formed from layers of GaAlAs, InGaAsP or InP. Semiconductor layers formed from InGaAsP transmit light in the range of 1300 to 1550 nm while InP layers transmit light at about 830 nm. The photochromic compounds described in the above patents will transmit light satisfactorily in these wavelengths and will not undergo reversal at these wavelengths.

It is also possible to integrate semiconductor lasers with a photochromic interconnection layer in accordance with this invention on the same chip. In such an application, the interconnection device need not be embodied in a fibre optic system.

Embodiments of the present invention will now be described by way of example, with reference to the accompanying drawings in which:-

Figure 1 shows a laser-modulator,

Figure 2 shows a simple structure according to the present invention,

Figure 3 shows an optical interconnection waveguide device formed in the structure of Figure 2 by selective conversion of a photochromic compound,

Figure 4 shows an alternative structure according to the present invention, and

Figure 5 shows a suitable apparatus for selective conversion of the photochromic material.

An example of the laser-modulator is illustrated in Figure 1. Semiconductor laser 10 and modulator 12 structures may be grown on common semiconductor substrate 14 (e.g. gallium arsenide or indium phosphide) or may be separately grown and then bonded to a common substrate, such as of glass, silica or PMMA: the technique described is appropriate in either case. Typically, a laser active layer 16 and modulator waveguides 18 may have different cross-section dimensions. The remaining layers in each structure will typically be grown with differential doping levels, rendering the waveguide characteristics of each different. It is clear that a grown interconnecting waveguide matching laser to modulator would be a difficult structure to produce.

The solution provided by the present invention is illustrated in Figures 2 to 4. Referring to Figure 2 a layer, or plurality of layers 20, of photochromic material are deposited by spin-coating or dip-coating. Preferably, many superimposed layers are deposited on the support 14, in order to build up a sufficient thickness of a few microns. It is found that, depending on the matrix material, many thin layers produce an optically better result than a single or a few thicker deposited layers.

The photochromic layer is formed by depositing thin plastic films a solution containing a polymer and a solvent. For example, in one case the solution was prepared by dissolving 2,5-dimethyl-3-furylethylidene (isopropylidne) succinic anhydride (see Example 1 of U.K. Patent No. 1,464,603 for preparation) in polymethyl methalcrylate (P.M.M.A.). 1 gram of the photochromic fulgide was dissolved in about 2.5 grams of PMMA and the resulting solution thinned with 10 mls of 2-ethoxy ethanol acetate (cellosolve acetate). A thin film was cast from this solution onto the support and dried by allowing the solution to flow onto the support 14 while it is held horizontally. The support is then turned vertically for a short, controlled time, e.g. 10-30 seconds to drain and then returned to the horizontal. After drying at a temperature in the range of about 40 to 60°C., a second coating of the solution is floated onto the support and the procedure repeated to build up a light-transmissive photochromic layer of desired thickness and having a surface which is sufficiently flat not to scatter the guided light wave in the waveguide.

An interconnection channel between the laser active layer 16 and waveguide 18 is then made by converting the initially low-refractive-index-state of the photochromic fulgide to the higher index state of its coloured form in a region 22 connecting the laser active region to the modulator waveguide, as depicted in Figure 3. For the photochromic fulgides, conversion to the higher refractive index-state is accomplished by exposure to UV radiation.

In accordance with the present invention selective conversion of the photochromic material to the coloured state is effected using a focussed beam of U.V. radiation and apparatus for moving the photochromic layer relatively to the focussed spot. Prior to forming the waveguide channels, it is important to ensure that the photochromic layer is entirely present in the colourless state. This is achieved in the case of the photochromic fulgides described above by exposing the layer to a beam of light in the visible range of about 450 to 550 nm. A suitable apparatus for producing the coloured waveguide channel 22 is shown in Figure 5. As can be seen in Figure 5 a collimated beam of light from a U.V. laser 51 passes through an electronic shutter 52 and reflected by a U.V. mirror 53 is focussed on the photochromic layer 55 by a lens 54 held in a focussing mount 56. The focussing lens is a microscope objective, typically × 10 magnification, and the focussing mount is an electrically driven moving coil positioner giving translation normal to the plane of the photochromic layer. By means of this movement, fine positioning of the beam in the depth of the layer can be achieved. A computer-controlled carriage is provided for supporting the photochromic layer and consists of two orthogonal translation stages and one rotation stage, each stepper motor driven with increments of 1 μm and 15 arc seconds. The absolute position of the platform is determined, when required, by means of capacitive compression probes. The stepper motors are driven under computer control which permits a wide range of waveguide patterns to be accurately written in the photochromic layer. The pattern of the interconnecting waveguide channels in the photochromic layer can thus be accurately matched to the semiconductor components in a reliable and reproducible manner.

This technique permits interconnection of initially misaligned components, since the photochromic

interconnection waveguide may incorporate angles and bends. This relaxes the tolerance on manufacture of the semiconductor components.

After the channel 22 has been formed, the whole device is hermetically sealed in a container or envelope which is opaque to light and excludes oxygen. This prevents the coloured form of the photochromic compounds in the waveguide channels reversing to the colourless form.

Figure 4 shows a modification of the structure shown in Figure 3 wherein the region between the component parts has a layer 24 of low refractive index material initially deposited, followed by the photochromic layer 26. The layer 24 may be deposited by any technique compatible with the semiconductors and might be, for example, an acrylic polymer deposited from solution by spin-coating or dip-coating, or a dielectric such as silicon dioxide deposited by sputtering or chemical vapour deposition. The addition of the low refractive index material permits increased confinement of the optical wave in the interconnecting waveguide, and improves isolation from the substrate.

It is to be noted, that the invention permits fine adjustment of the interconnection after it is made. Since the photochromic remains active under influence of light in its absorption bands, fine adjustment is possible to the position and characteristics of each waveguide which aids optimisation.

The present invention enables the production of waveguide optical interconnection devices which have low propagation losses in the wavelength range 1-1.6 μm. Using computer control of a U.V.laser writing system, the waveguide channels in the photochromic layer may be precisely aligned between arbitrary end points, and may include curves or bends. When deposited as an overlayer on existing separated waveguide components, sources, or detectors, the written channels may form interconnections.

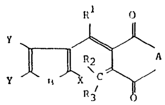
When used as an interconnection technique, advantages are simplicity and relaxation of alignment and fabrication tolerances. The technique may be employed with any waveguide system. Where the original substrate is of higher refractive index than the photochromic interconnection, an intermediate lower refractive index isolating layer may be employed.

The invention has a particular application typified by the example of a semiconductor laser and modulator grown on a common substrate. The layer growths for these two devices may or may not be similar. There is a requirement to interconnect the two by an optical waveguide. The waveguide may be grown, but this approach is complicated probably giving low yield. The present invention provides an alternative interconnection technique that offers (i) simplicity; (ii) low cost; (iii) tolerance relaxation in manufacturing the component semiconductor parts in alignment; (iv) high yields; (v) flexibility.

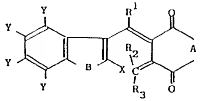
CLAIMS

1. An optical interconnection device which comprises two or more guided wave components located on a common support and a layer of a photochromic material disposed between said components, said photochromic material being capable of conversion between coloured and colourless states which have different refractive indices, and said layer having at least one waveguide channel which optically connects said components and which is formed in said layer by selective conversion of the photochromic material in the region defining the channel to a state different from that of the bulk material.

2. A device according to claim 1 wherein the photochromic material comprises a fulgide or fulgimide having the general formula (I) or (II):-



(I)



(II)

wherein A represents oxygen or $>NR_4$, R_4 being hydrogen or an alkyl, (including cycloalkyl), aryl or aralkyl group;

R_1 represents a hydrogen or an alkyl or aryl group;

R_2 and R_3 independently represent any alkyl or aryl group or one of R_2 and R_3 represents hydrogen and the other represents an alkyl or aryl group;

B represents oxygen or sulphur;

X represents hydrogen or an alkyl, aryl or aralkyl group; and

each Y is the same or different and is independently selected from hydrogen, halogen, alkyl, aryl, alkoxy and aryloxy groups.

3. A device according to claim 2 in which the group represented by

$$\begin{matrix} R_2 \searrow \\ C = \\ R_3 \nearrow \end{matrix}$$

in formulae (I) or (II) is replaced with an adamantylidene group.

4. A device according to claim 2 or 3 in which the waveguide channel comprises a region in which the fulgide or fulgimide is in its coloured form, the refractive index of which is higher than that of the uncoloured fulgide or fulgimide.

5. A device according to any one of the preceding claims in which the guided wave components are semiconductors.

6. A device according to claim 5 in which the semiconductor components comprise a laser semi-conductor and modulator.

7. A method of making an optical interconnection device which comprises depositing on a support having two or more guided wave components thereon, a layer comprising a photochromic compound dissolved or dispersed in a carrier composition to form a solid, light transmissive photochromic layer, said photochromic layer being capable of conversion between coloured and colourless states which have different refractive indices and forming at least one waveguide channel in said layer, which optically connects said components by selectively converting photochromic material in a region defining the channel to the coloured state.

8. A method according to claim 7 wherein the photochromic material comprises a fulgide or fulgimide, having the general formula (I) or (II) set forth in claim 2, and the waveguide channel is formed by focussing a U.V. laser beam on the layer.

9. A method according to claim 8 in which the photochromic layer is produced by dissolving the photochromic compound in a polymer solution or dispersion, depositing a film of the solution or dispersion on a support and drying the film to form the layer.

10. A method according to claim 7 in which a plurality of superimposed films are cast on said support, to build up said photochromic layer, each film being dried before deposition of the succeeding film.

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